COMPARISON OF PREDICTIVE METHODS FOR STRUCTURAL RESPONSE TO HE BLAST LOADS

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ABSTRACT

Numerous methods for predicting structure response to airblast caused by HE explosions were developed during the last twenty years. The rigor, complexity and sophistication of the methods are known to cover a wide spectrum. Some the less complex but widely accepted methods are examined, assessed, and discussed relative to their degree of conservatism. To support their assessment, the authors critically examined the structural design parameters used in the predictive methods.

BACKGROUND

The Corps of Engineers, as the Army's designer and builder of military facilities, maintains a continuing interest in the technology of the effects of weapons and explosions on structures. The earliest design techniques were related to projectile penetration and then came the great interest in effects of nuclear weapons including blast, shock, and other associated effects. During World War II, there developed relatively crude procedures usually "rule of thumb" methods to estimate effects of accidents at the many munitions and explosive manufacturing facilities which we rapidly erected during the period 1941-1945. In the last 30 years, problems of design of structures to resist the effects of HE explosions have been addressed on a more rational basis.

Two of the most recent non-nuclear documents reflecting the Corps' efforts are TM 5-1300, Structures to Resist the Effects of Accidental Explosions (1969), and HNDM-1110-1-2, Suppressive Shield Design and Analysis Handbook (1977). These documents, among other Corps references, provide our basic guidance. However, the Corps design activities have not been restricted to these two documents.

Many methods conforming to other authorities are also used. Some of the most frequently used methods are: (1) ASCE Manual 42, (2) Air Force Manual 500-8, (3) Defense Civil Preparedness Agency (now Federal Emergency Management Agency) Protective Construction, and other texts usually associated with structural dynamics.

APPROACH

Our experience with HE explosions typically centers on three basic types of airblast loading: (1) pressure-time (triangular), (2) impulsive, and (3) the combination of impulsive and pressure-time loading as shown in Figure 1.

Accordingly, each of these loads was separately included in the analysis. It was considered important that these loads be treated separately in view of possible variances in conservatism in the methods under the different loading.

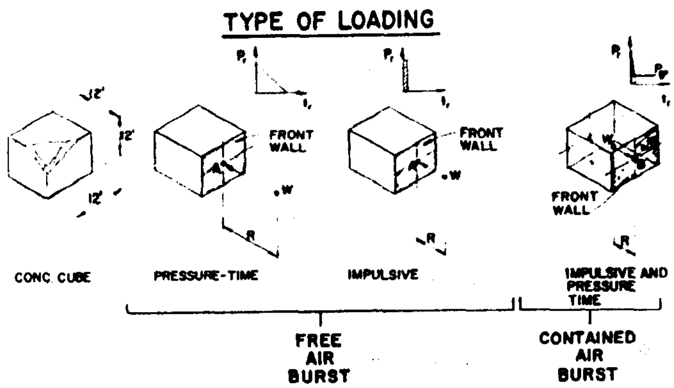
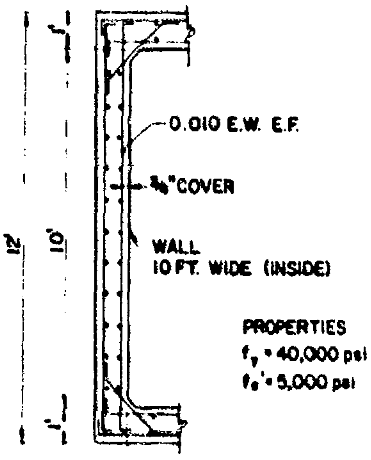


Figure 1

Since reinforced concrete prevails among protective structures, we selected a reinforced concrete wall as the structural element for our assessment of the methods. After determining the loads and the structural elements, we proceeded with our analysis.

STRUCTURAL CAPABILITY

The two-way reinforced concrete wall in Figure 2 was designed for flexure as indicated by the main reinforcement. No shear calculations were made. For our purpose, it is assumed that shear may be adequately provided. Flexural strength and other structural properties are tabulated in Table 1. These were used as the basis for calculating deflection used in our comparison.



REINFORCED CONCRETE WALL (TWO-WAY SLAB)

Figure 2

TRIANGULAR LOAD

A family of curves is plotted for the reinforced concrete wall to predict the wall deflection resulting from a triangular pressure-time load. Each curve represents a specific ductility ratio, u, hence deflection. See Figure 3.

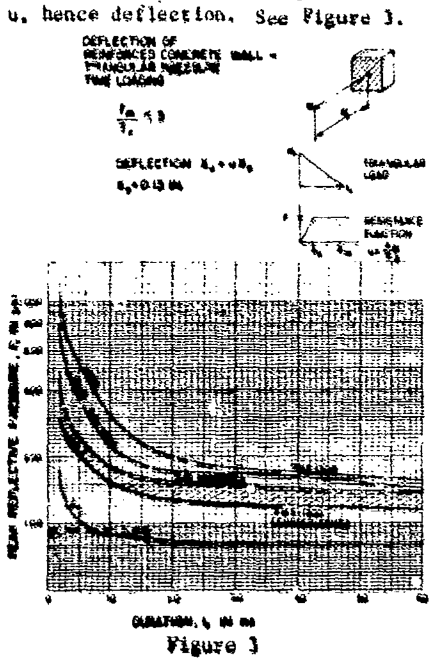


Figure 3

By locating the coordinate (t_d, P_r), the ductility ratio may be estimated by interpolating between the u's. For a ductility ratio, u = 3, two curves are shown; one for TM 5-1300 method and the other for the suppressive shield method. All the other methods previously discussed are distributed in the shaded band. A close observation indicates that the TM 5-1300 curve is more conservative than the others, because being on the lower side of the shaded band it has more restrictions on the limits of pressure and duration for the given ductility ratio, u = 3. The Suppressive Shield Handbook curve is less restrictive, allowing 25 percent higher pressures for the same duration and ductility ratio.

IMPULSIVE LOAD

When the wall is impulse sensitive from close-in explosions, deflections are also predictable. Based on the curves in Figure 4, the TM 5-1300 curve on the lower side of the shaded band is conservative because being on the lower side of the shaded band, it has more restrictions on the limits of the impulse for a given deflection. The Suppressive Shield Handbook curve is less restrictive allowing 20 percent higher impulse for the same deflection. Curves for the other methods are distributed within the shaded band.

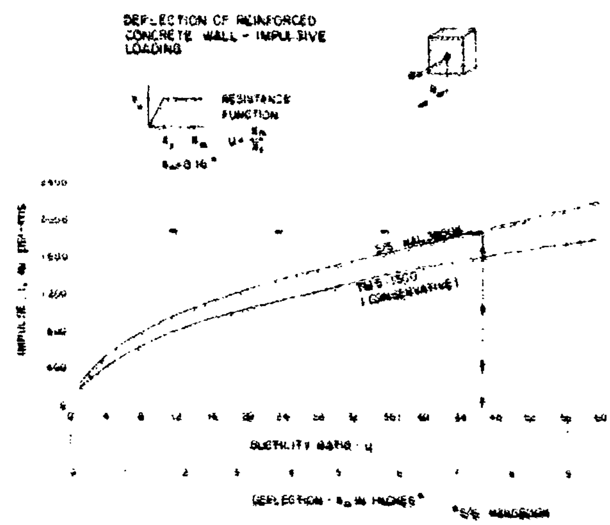


Figure 4

COMBINED LOAD

The combined load consists of an impulsive load followed by a prolonged gas pressure. A family of curves is shown in Figure 5 and each curve represents a specific ductility ratio, u.

After locating the coordinate (P_{gs}, i_r), the ductility ratio, u, can be estimated by interpolation between u's. The ductility ratio curve u = 3 for TM 5-1300 and the Suppressive Shield Handbook methods are shown. It can be demonstrated again that the TM 5-1300 curve on the lower side of the shaded band is more conservative than the Suppressive Shield Handbook curve on the upper side of the band. TM 5-1300 is more restrictive on the limits of impulse and gas pressure for a given ductility ratio, u = 3. The Suppressive Shield curve is less restrictive allowing 15 percent impulse or 30 percent higher gas pressure for the same ductility ratio.

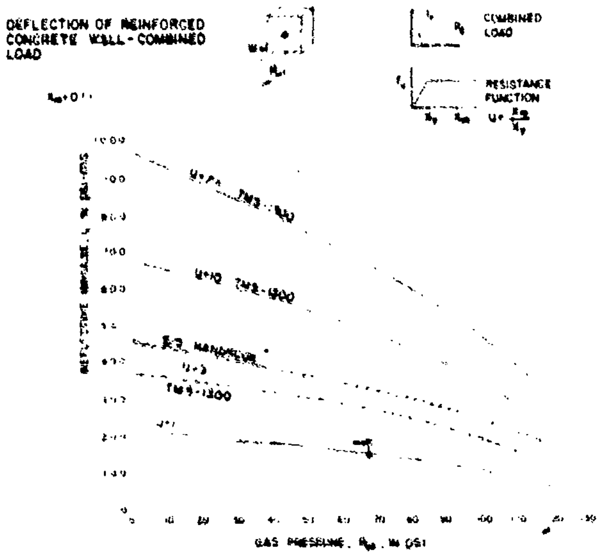


Figure 5

EXAMPLE

The charge weight, distance and load parameters are shown in Figure 6. These numbers provide an appreciation for the magnitude involved and an understanding of the curves. Applying load parameters on the wall, deflections are estimated by using Figures 3, 4, and 5. These examples are not restricted to any one method, i.e., both TM 5-1300 and Suppressive Shield methods are used below.

For the 8000# TNT at 100 feet, where P_r = 90 psi and t_r = 16 ms, select from Figure 3 (TM 5-1300 curve) approximate u = 1.4 or $X_m = uX_y$ = 1.4 x 0.13 in. = 0.2 in. For the 512 lb. TNT at 10 feet, where i_r = 1920 psi-ms, select from Figure 4 (Suppressive Shield curve) X_m = 7.4 in.

For the contained 8 lb. TNT at 5 feet, where i_r = 184 psi-ms and P_{gs} = 64 psi, select from Figure 5 (TM 5-1300 curve) approximate u = 1.3 or X_m = 1.3 x 0.13 = 0.2 in. These deflections compare well with the calculated X_m in Table 1.

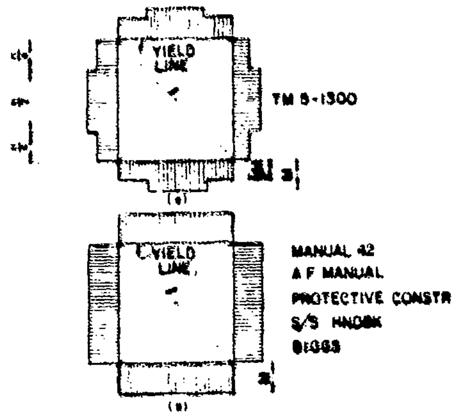
ASSUMPTIONS

Four factors influence the differences in the predictive methods; yield line assumption, moment of inertia, modulus of elasticity and stiffness. As expected, the variance within these factors are the basis for the differences in the predicted deflection.

YIELD LINE

In most two-way slab designs, the effective unit resisting moments are assumed to be uniformly distributed on the yield lines. In TM 5-1300, the effective resisting moment at the corners are reduced by one third. This reduction causes the TM 5-1300 method to be significantly conservative. See Figure 7.

TWO-WAY SLAB
YIELD LINE DISTRIBUTION OF MOMENTS



MOMENT OF INERTIA

The formulas for moments of inertia are shown in Figure 8.

FORMULAS FOR MOMENT OF INERTIA
(REINFORCED CONCRETE SLAB)

$$I_a = \frac{bT^3}{24} + \frac{b(k'd)^3}{6} + \frac{npbd^3(1-k)^2}{2} \quad \text{TM 5-1300}$$

$$I_a = \frac{bd^3}{2}(5.5p + 0.083) \text{ (APPROX.)} \quad \text{S/S HNDBK, BIGGS, A F MANUAL}$$

$$I_a = \frac{bd^3}{24} + \frac{b(k'd)^3}{6} + \frac{npbd^3(1-k)^2}{2} \quad \text{MANUAL 42, PROTECTIVE CONSTR}$$

Figure 8

Appreciable difference in I_a appears when the slab thickness is small. This is attributable to the use of "T" in TM 5-1300 and "d" in the other methods.

MODULUS OF ELASTICITY

When 3600 psi concrete is specified, the E_c in Figure 9 is the same for all methods. See intersection of curves.

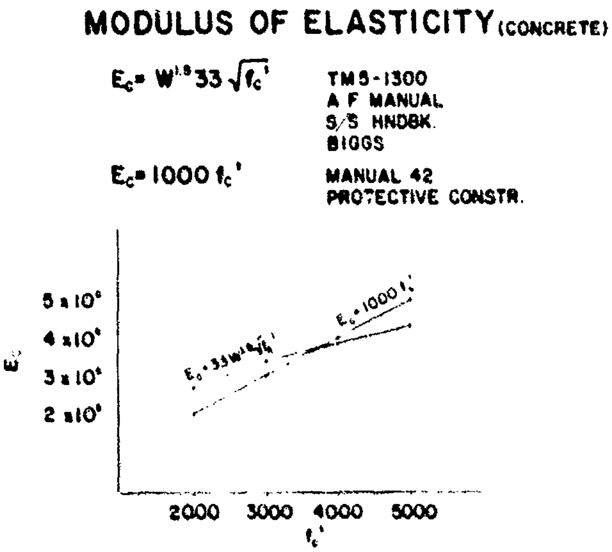


Figure 9

Since most concrete strength for airblast loads exceed 4000 psi, a difference in modulus of elasticity is unavoidable.

STIFFNESS

With the exception of protective construction and Manual 42, the equivalent stiffnesses are used. From our preceding example, the stiffness by Manual 42 is significantly higher as shown below:

Manual 42 Protective Construction $$k = 807\left(\frac{\frac{E_c I_a}{4}}{L_a}\right)$$

Others $$k = 605\left(\frac{\frac{E_c I_a}{4}}{L_a}\right)$$

DISCUSSION

The assessment on the relative conservatisms are based on airblast data from TM 5-1300 curves. The more recent data in the Suppressive Shield Handbook is significantly different. The difference in impulse is seen in Figure 10. TM 5-1300 is as much as 60 percent higher.

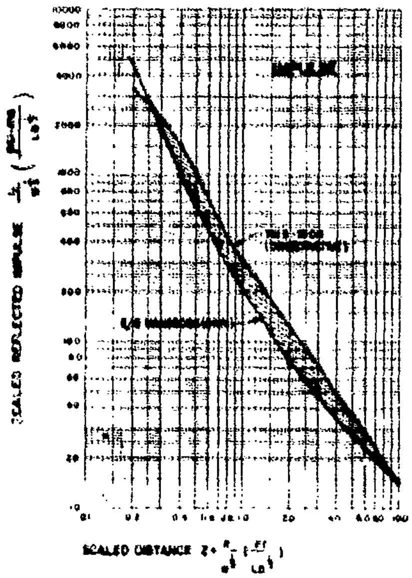


Figure 10

If the latest data were separately used in the Suppressive Shield Handbook method, the differences in conservatism between methods would be more pronounced.

We have examined the extremes in the predictive methods. Of the six methods, no comparison was made as to how new each related to the other in conservatism. The best basis for judgement is the comparison of deflections in Table 1.

In our examination of the methods, we assumed all methods are conservative. This assumption is supported by testing of full scale and model structures in previous Army programs associated with the development of Corps of Engineers manuals for hardened structures. Accordingly, we consider the assumption to be reasonable.

CONCLUSION

In assessing the relative conservatism of the methods, the focus was on both ends of the spectrum; the most conservative on one end and the least conservative on the other. We identified the TM 5-1300 method as the most conservative and the Suppressive Shield Handbook method as the least conservative.

Based on the maximum deflection, X_m, in Table 1, the order of conservatism beginning with most conservative to least conservative follows:

1. TM 5-1300
2. Manual 42
3. Protective Construction
4. Air Force Manual
5. Biggs
6. Suppressive Shield Handbook

In general, because of similarity, it would be more appropriate to group conservatism as follows: TM 5-1300 by itself as the most conservative; Manual 42, Protective Construction, and the Air Force Manual in the intermediate group; and Biggs and the Suppressive Shield Handbook as the least conservative group.

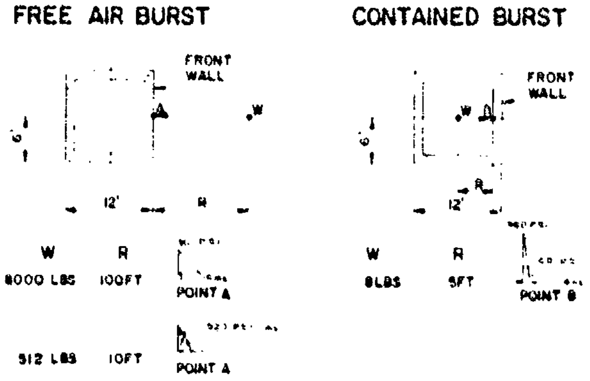


Figure 6

Table 1

COMPARISON

(DESIGN PARAMETERS OBTAINED THROUGH DIFFERENT DESIGN METHODS)

METHOD / PARAMETER	TM5-1300	MANUAL 42	AF MANUAL	PROTECTIVE CONSTR	S/S HNDBK	BIGGS
MOMENT OF INERTIA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MODULUS OF ELASTICITY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
STIFFNESS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PERIOD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PLASTIC MOMENT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ULT RESISTANCE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ELASTIC DEFLECTION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]			[illegible]	[illegible]	

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